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SYNOPSIS: A portion of a slope of a subsurface waste containment cell failed. It is believed that this failure could be attributed to a sudden drawdown condition caused by the pumping of treated wastewater effluent stored inside the cell prior to construction of the permanent liner. This conclusion seems to be in agreement with the results of a stability analysis conducted utilizing post-failure slope profile data. A discussion of the analysis of the failure and the reconstruction of the slope is presented in this paper.

INTRODUCTION

The waste containment cell referred to in this paper is located somewhere in the northeastern United States. The purpose of this earthen containment is to store hazardous solid wastes. Figure 1 shows a typical cross section of this structure. The bottom and the sides of the containment cell are lined with a 2 foot thick soil liner consisting of compacted glacial till (clay), and a 10 mil thick impervious membrane liner.

GEOLOGY AND SUBSURFACE CONDITIONS

The surficial deposits in the area are of glacial and glacio-fluvial origin. They are reported to be about 50 to 60 feet thick and are underlain by bedrock, which is a shale formation. The glacial soils are comprised of a dense glacial till of sufficient shear strength to be stable under the 2:1 slope configuration of the containment structure. Occasional lenses of varved silts and silty clays of low shear strength known as glacio-fluvial clays have been encountered within the till deposit. In the area of the containment structure, borings performed prior to construction indicated that glacio-lacustrine clays were encountered at or below the level of the bottom of the containment cell.

SEQUENCE OF EVENTS PRIOR TO FAILURE

The sequence of events preceding the failure of the slope is presented in Table 1.

TABLE 1

Elapsed Time (months)	Event
0	Excavation for containment commenced
6	Excavation for containment completed
6	Treated wastewater effluent was temporarily ponded to a maximum depth of 15 feet in the unlined containment cell excavation
12	Ponded liquid pumped out very quickly
13	Liner installed
14	Solid waste placed in center of containment cell
17	Limited slope movement observed by maintenance personnel
18	Treated wastewater effluent ponded again inside the containment cell to a maximum depth of 6 feet
24	Ponded liquid pumped out quickly
25	Failure of slope observed by on-site personnel

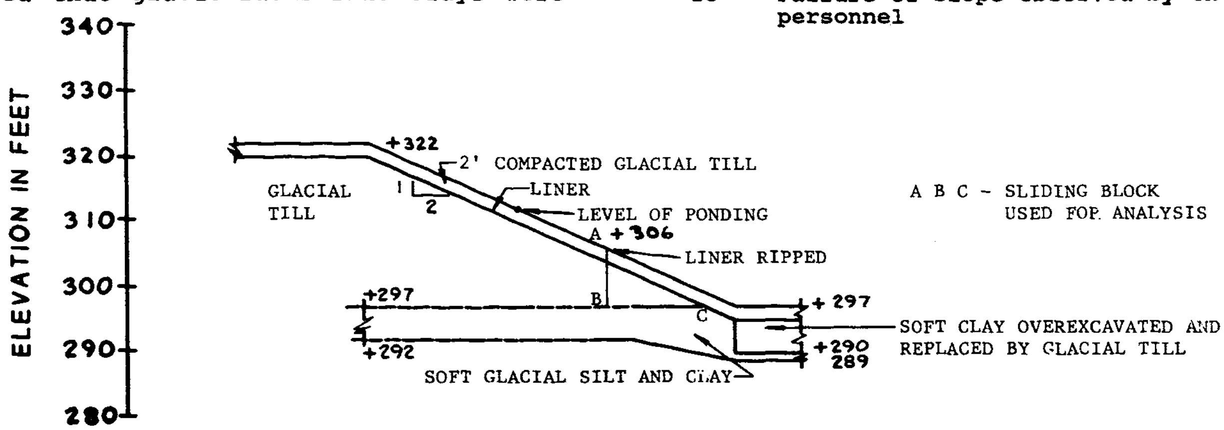

FIGURE 1 – CROSS SECTION OF NORTH SLOPE

POST-FAILURE INVESTIGATIONS

In order to determine the cause of failure and to design remedial work to be performed on the slope, a post-failure investigation of the slope was undertaken. This consisted of: 1. Field investigations to survey and observe the conditions after failure and to determine the nature and the extent of failure; 2. Testing to determine the properties of the embankment and liner soils; and 3. Stability analysis of the slope.

FIELD INVESTIGATIONS

These consisted of several site visits to the site by the authors, surveyors and other technical personnel. Figure 2 shows the details of conditions observed. Two test pits and several hand-excavated holes were excavated in the vicinity of failure to observe the soils and expose the liner. Soil samples from the liner materials and underlying natural soils were obtained for testing. Some undisturbed tube samples of soft clay were obtained from locations in the vicinity of failure. At selected stations along the north-central slope, survey cross sections of the slope were obtained. A typical post-failure slope profile is shown in Figure 3.

OBSERVATIONS BASED ON FIELD INVESTIGATIONS

Based on the above investigations, the following observations were made:

1. The soil above and 6 inches below the membrane liner was saturated.

2. The membrane liner separated along a seam near the top of the slope approximately in an east-west direction and no rips were noted near the top of the slope.

3. The membrane liner was ripped at an elevation approximately 8 to 10 feet above the bottom of the landfill cell.

4. The bottom of the cell adjacent to the toe of the slope heaved to a distance of 15 feet horizontally from the initial toe of slope.

5. In the region near the bottom of the cell, the underlying natural clays heaved up over the compacted glacial till liner soils.

6. The slope moved horizontally in the region between the elevation where the membrane liner ripped and the bottom of the containment cell slope.

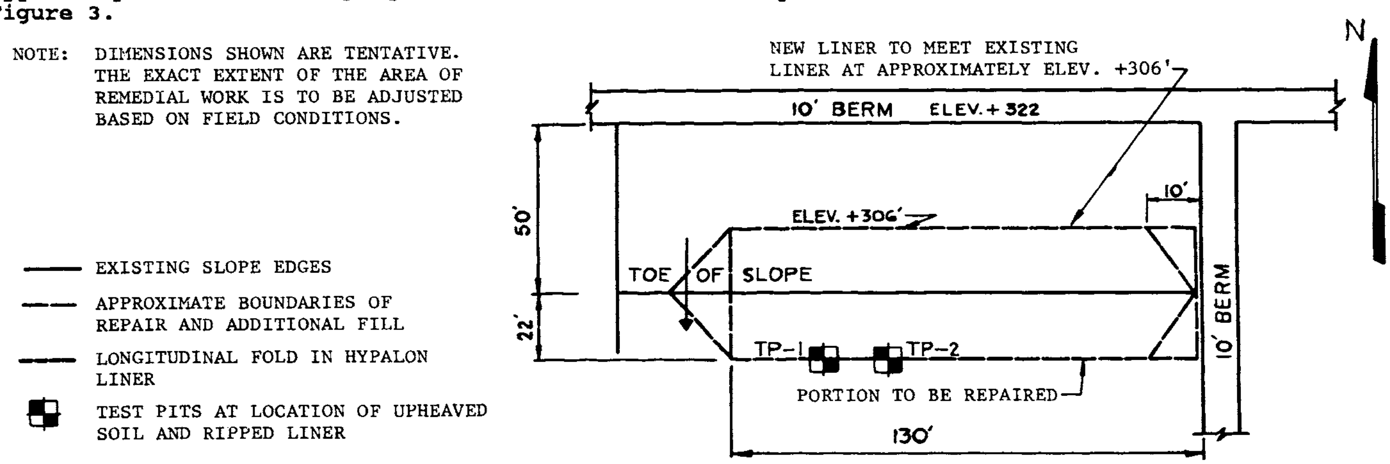

FIGURE 2- PLAN VIEW OF THE CENTRAL PORTION OF THE NORTH SLOPE SHOWING CONDITIONS AND THE EXTENT OF REMEDIAL WORK TO BE DONE.

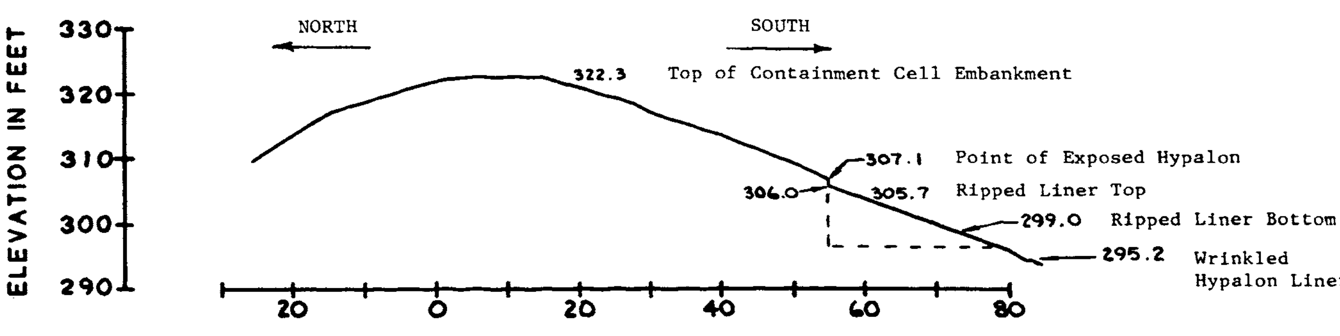

FIGURE 3- TYPICAL POST-FAILURE SLOPE PROFILE

7. Some secondary laminar movement of the slope above the elevation where the liner ripped was also observed.

PROPERTIES OF SOFT SOILS

Index tests and unconfined compression tests were performed on the undisturbed tube samples recovered from the site. The average Liquid Limits and Plastic Limits were 30% and 15%, respectively. Natural water contents were close to the plastic limit. The materials exhibited characteristics of a silty clay. Average unconfined compressive strengths in the undisturbed and remolded conditions were determined to be 460 psf and 110 psf, respectively.

STABILITY ANALYSIS

From the boring logs, there is evidence that a soft layer of glacio-lacustrine silt and clay underlies the surficial glacial till. Test pits made at two locations, shown in Figure 2, indicate that the contact between the soft layer and the till occurs at an elevation of approximately +297 feet. At this elevation, the liner was observed to have displaced horizontally. Hence it was presumed that failure occurred along the glacial till-soft soil contact.

A sliding block analysis for a sudden drawdown condition (assuming no internal friction) as recommended in the literature (Taylor 1959, Sherard et. al. 1963, and Lambe and Whitman 1964) was performed. Since data regarding pore pressures at the time of failure was not available, a total stress approach was utilized. Cohesion required in the soft clay for stability of the base was determined to be about 330 psf, whereas the soft soil had an unconfined compressive strength of 110 psf in the remolded condition.

CAUSE AND MECHANISM OF SLOPE FAILURE

Based on the analysis, it was concluded that the lower portion of the slope above the soft clay-glacial till contact slid horizontally. This caused a portion of the glacial till above this contact to drop. In this process, the membrane liner along the slope sheared. The limited failure of the liner near the toe in the bottom of the containment could be attributed to localized upward and horizontal movement of the soft clays from under the slope to the toe causing shearing of the membrane liner. It is felt that the slope would not have failed if: 1. the unlined containment cell had not been flooded with treated effluent prior to installation of the liner; and 2. the toe of the north slope had been restrained by waste fill materials soon after construction of the liner. The remaining portions of the containment cell where waste fill was placed soon after installation of the liner experienced no slope movements.

RECOMMENDATIONS FOR REMEDIAL CONSTRUCTION

Two alternates were proposed for the remedial construction of the slope. The details of the first alternate are shown in Figure 4. In order to reconstruct the limited portion of the north slope to its original configuration, the disturbed soft clay soils within the area of the toe of the slope would have to be removed. A stable slope configuration, as initially constructed, would require overexcavation and replacement of soft clay soils to a depth of approximately six feet at the toe of the slope, as well as up the side of the slope, to the contact with the overlying glacial till. The overexcavation work would require that limited areas be excavated and filled with suitable compacted material in order to minimize potential slope failure during remedial earthwork.

Details of the second alternate proposed are shown in Figure 5. Implementation of this solution would require that the disturbed soft clay soils be removed to the initial slope configuration and a layer of compacted glacial till at least 4 to 5 feet in thickness be placed above the toe of the north slope prior to replacing the membrane liner. This solution would flatten the final slope in the region of the disturbed soft clays, and would provide a blanket of compacted fill above the in-place soft clay soils to minimize the effects of future settlements due to consolidation of the underlying soft clays. It is felt that this alternate would provide a suitable base for the reconstruction of the liner without creating potential safety hazards during remedial construction which would be involved with any

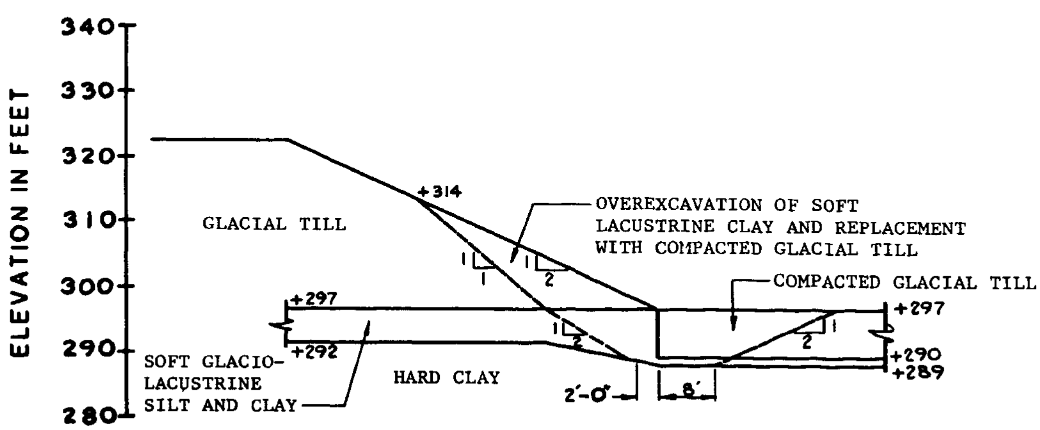

FIGURE 4– NORTH SLOPE REMEDIAL WORK – ALTERNATE NO. 1

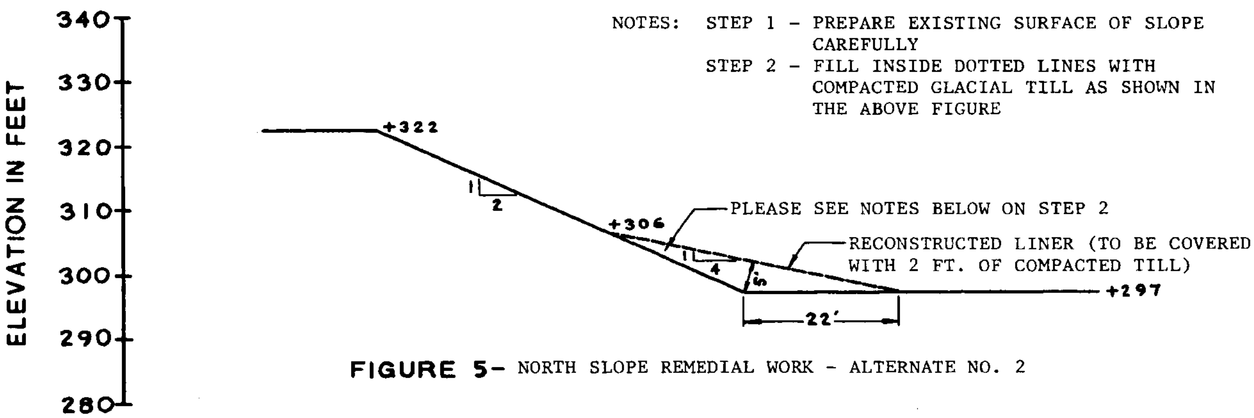

FIGURE 5- NORTH SLOPE REMEDIAL WORK - ALTERNATE NO. 2

extensive overexcavation of the soft clays. Hence, this alternate was selected for the remedial construction.

OTHER DETAILS OF REMEDIAL WORK

The following are some other relevant details of remedial work:

1. The soft disturbed glacial till materials should be excavated to the initial slope configuration within the area to be repaired.

2. Following the removal of the disturbed soils, glacial till material should be spread in loose lifts approximately 12 inches in thickness.

3. Each lift of fill should be compacted to at least 90% of its maximum dry density (ASTM D-1557).

4. The compacted glacial till should be placed within the limits shown on Figure 2 to the slope configuration shown on Figure 5.

5. Upon completion of the placement of the compacted glacial till, the membrane liner should be reconstructed on the top of the glacial till and sealed to the existing membrane liner around the perimeter of the area to be repaired.

6. A final 2 feet thick layer of compacted glacial till should be constructed above the new liner in accordance with the original design plans.

7. It is suggested that the final exposed layer of glacial till be moisture conditioned as required to avoid shrinkage cracks prior to burial within the cell. The exposed glacial till layer beyond the limits of the liner repair may also require moisture conditioning and/or recompaction.

The work was completed according to the above specifications and the containment structure has performed satisfactorily without additional slope movements.

CONCLUSIONS

From the post-failure investigation, it can be concluded that the slope of the containment cell failed due to a sudden drawdown type of condition caused by the pumping of the liquid wastewater effluent. This failure could have been avoided, if the inside of the pond were lined prior to ponding of treated wastewater effluent, and/or if the containment cell were filled with solid waste soon after the construction of the liner. This case history demonstrates the importance of developing an operations manual for waste facilities at the time of design and construction.

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